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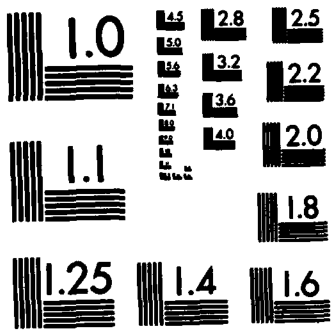

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Die Entwicklung von Primaerelementbatterien fuer Torpedos und Kleinst-U-Boote in Deutschland

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THE DEVELOPMENT OF PRIMARY CELL BATTERIES FOR TORPEDOES AND MIDGET SUBMARINES IN GERMANY

[Roessler, Eberhard; Die Entwicklung von Primaerelementbatterien fuer Torpedos und Kleinst-U-Boote in Deutschland; Marine-Rundschau No. 6, 1982, pp. 317-321; German]

The experts for German submarine construction in the Second World War with this contribution present a report on technology especially important for the development of torpedoes and midget submarines on which little information was to be found in the past in the literature. /317*

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Torpedo Developments

The electrically powered [E] and thereby wakeless torpedo was developed during the First World War by the Siemens Company. There it was their goal initially to produce a remote-controlled torpedo. At war's end, an E/7 torpedo was in the test stage which with one storage battery made a 1500-m run at 26.5 kn and a 2000-m run at 20 kn. This torpedo was never deployed. After the war, the E-torpedo was further developed by the Siemens and the AFA Companies.

Starting in 1934, a new battery-powered torpedo was produced especially for employment on submarines by the TVA [Torpedo Test Facility] in collaboration with those companies under the designation G 7e, which with battery 13 T 210 in two trays made a run of 5000 m at 30 kn. The main requirement for further development of the E-battery was a further increase in the range and speed. Besides the increase in size at the cost of greater negative buoyancy. the use also of primary cells instead of lead storage batteries was begun.

In 1941 a primary cell battery was proposed by Dr. Koehler (Chemical-Physical Research Institute--CPVA, Kiel) for the battery-powered torpedo which was equipped with one carbon and one magnesium electrode. Dilute nitric acid with a chronic acid admixture as a depolarizer was to be used as the electrolyte. The goal was to attain a considerably higher capacity and thereby a three to four-time increase in the range of the torpedo with this battery over the lead storage battery used until then in the torpedo battery 13 T 210. The following additional advantages were mentioned besides:

No battery maintenance and no oxyhydrogen gas formation during storage, since the electrolyte did not reach the electrodes until the torpedo was fired;

Savings in lead, a very favorable feature at that time from the point of view of raw materials.

The laboratory tests were conducted by the CPVA in collaboration with the TVA in Eckernfoerde. In the early tests, 20% nitric acid with a 15% chromic acid admixture was used. The positive electrode was developed in collaboration with the Siemens-Plania Company; the Mg electrode was made from AZM or AM 503 magnesium plate.

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*Numbers in the right margin indicate pagination in the original text.

Drawing, top, left:

Diagram of the battery installation of the 42 AII (Mg-C)

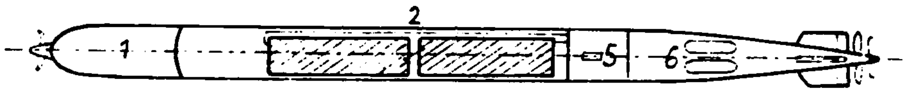
1. Electrolyte container (275 l)
2. Battery (Mg-C)
3. Compressed air bottle
4. Centrifugal pump
5. Compressed air valve
6. Regulator with motor
7. Exhaust blowing valve
8. Opening lever
9. Torpedo motor
10. Electrolyte cooler

The electric torpedo equipped with an Mg-C battery of this type was designated the 42 AII. It had the dimensions of the G 7e. Its other characteristics were:

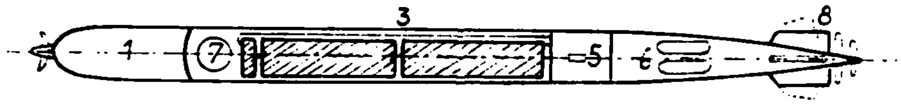
	Head	Whole torpedo
empty	233 kg	1282 kg
full	374 kg	1650 kg
Water displacement		1314 l
Water capacity		141 l
Negative buoyancy		20.4 %

A run of 9000 meters was calculated at a speed of 30 kn.

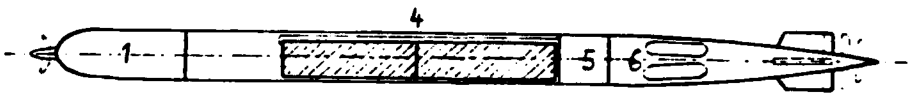
Torpedo G 7e — II (Gerät 20)



Torpedo G 7e — IIIa (Gerät 20)



Torpedo G 7p (Gerät 42P)



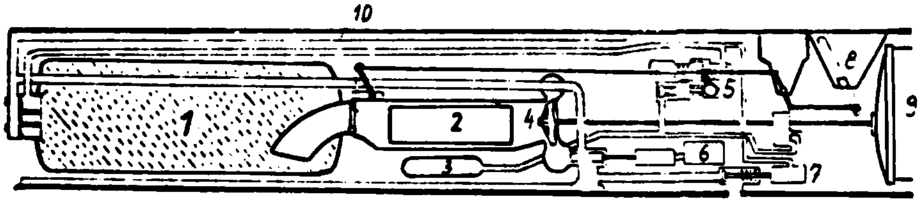
Drawing, bottom

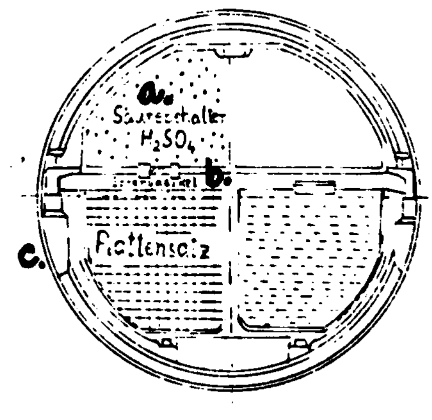
1. Warhead (280-kg charge)
2. Battery 13 T 210:52 cells with 13 positive plates each (650 kg)
3. Battery 17 T 210: 54 cells with 17 positive plates each (830 kg)
4. Primary battery $Pb-O_2-Zn$
5. Electric motor (107 kg)
6. 3 air bottles of 5 l each (200 atm)
7. Additional air container
8. Removable vertical fins

At first it was planned to install 40-50 cells, which were able to be made quite small, in a 13 T battery tray, which, owing to the high current capacity of the Mg-C cell, was now enough for motive power. The space of the second tray in the battery-powered torpedo was needed for the container of the required nitric and chromic acids as well as for the circulating pump. The cell cases of aluminum plate were to receive two carbon and three magnesium electrodes each. Difficulties with the current lead-offs in the case covers, however, led to the abandonment of this structure of the battery early in October 1941. It was decided to build the Mg-C battery on the principle of the Voltaic pile. Such a battery was fabricated by the TVA in which discs with a 400-mm diameter were piled on a pertinax tube, which at the same time was to serve to carry the electrolyte. A uniform interval of 4-5 mm was attained by using synthetic pads between the plates. This battery was said to be able to deliver with its electrically effective total area of 1000 cm^2 a current of about 1000 A, which corresponds to the average amperage of the G72 motor during the 30-kn run.

Late October 1941, IG Farben AG in Bitterfeld then received an order from the TVA to produce 10 batteries of that type. During the preliminary work, it turned out that the originally provided Siemens carbon electrodes were not suited for the bipolar plates. Siemens dropped out of this development and began the parallel development of an Mg-C primary battery. But it is not known how far that work progressed.

Now IG Farben itself produced carbon electrodes with an aluminum substrate, onto which the Mg plates were able to be pressed with the aid of zinc foil. Since the plates which had been pressed together sometimes came apart after some time, the bonding method had to be changed. These bipolar electrodes initially attained only 0.6 W/cm^2. As a result of a further improved production method, this value was finally able to be increased to 2 W/cm^2. Another difficulty was presented by the low electrolyte speed between the electrodes of the disk battery. IG Farben thereupon proposed making the whole set of electrode plates as a centrifugal pump rotor. However, this suggestion was not accepted by the TVA, since it would have meant too large rotating masses in the torpedo. They proposed to have the electrolyte flow through the electrode plates in the longitudinal direction of the torpedo. The first battery of this design for a torpedo output of 220 hp maximal was manufactured in spring 1942. Major cooling problems arose during testing, since a cooling area of 4 m^2 was required. As of summer 1942 there began the work on the configuration of the torpedo of this installation. The required components such as the cooler, electrolyte container and centrifugal pump were ordered. Further testing and impovement of the acid circulation was assigned to IG Farben. In the G 72 type torpedo. 275 liters of electrolyte had to be carried. The rated voltage was placed at 90 $\pm$ 4 V. The voltage drop during operation resulting from electrolyte impoverishment was supposed to be counteracted by heating the electrolyte. An appropriate voltage regulator was made by the Hagenuk Company in Kiel for that purpose. /318





a. [illegible]cid container
b. Cover for explosive
c. Plates

Cross section through the battery of Device 42P
($Pb-O_2-Zn$)

At the end of 1943 a torpedo was equipped for the installation of the Mg-C battery. The shells were available for nine more. By order of the Torpedo Committee, a total of five torpedoes were to be made for firing tests. The first firings were to take place in February 1944. However, not until late July were all the individual parts available for five torpedoes at the TVA in Eckenfoerde. The tests were conducted in the period between 25 August and 12 September 1944. The electrolyte composition for those tests consisted of 400 g nitric acid and 200 g chromic acid per liter of electrolyte. The run was limited to 3000 m. But the tests were not successful. One torpedo did make a 4500-m run, but had trouble when running deep and with heeling, which was presumably caused by fluctuations in voltage resulting from irregular electrolyte circulation. Two rounds ended in a premature interruption of the torpedo run, presumably also as a result of circulation problems, while the remaining two torpedoes were tube runners. However, there was no danger when that happened.

Since after that the safe employment of this torpedo could not be expected in the foreseeable future, owing to the critical war situation the work on this torpedo was discontinued by decision of the Torpedo Committee at the TVA, as well as at IG Farben.

The slow production of the 42 II in 1943 may, in addition to technological difficulties and personnel shortages, possibly have been caused by the fact that on the one hand in that time there had been success in coping with the greater negative buoyancy in the G 7e with removable vertical fins and thus be able to use the 180-kg 17 T 210 battery, whereby the range at 30 kn was able to be increased to 7500 m, and on the other hand in early 1943, a simpler primary battery based on the Zn-PbO_2 system had been suggested by Professor von Steinwehr (PTR - Physikalisch-technische Reichsanstalt in Berlin), which was now being conducted as a parallel development by the PTR, the AFA (Akkumalatorenfabrik AG, Berlin and Hagen/Westf.), and the TVA.

The AFA had already thoroughly pursued the zinc-sulfuric acid-lead dioxide system in 1926-32 and 1935-36, but as a rechargeable secondary battery. Owing /319 to the self-discharge of the zinc electrode in the sulfuric acid because there was no means to inhibit it, the higher energy storage over the standard lead storage battery was usable only when the discharge occurred immediately after charging. Therefore, this battery was unusable for most purposes, and further development was discontinued. Now when in February 1943 the received an order from the PTR to develop a primary cell on this basis for the torpedo, they were able to immediately pick up the preliminary work and in a relatively short time produce a Zn-PbO_2 battery.

As with the Mg-C cell, the battery is not filled with the electrolyte until immediately before use. In order to reduce the disintegration on the zinc then setting in under an intense evolution of hydrogen, the zinc electrodes were given an Almagen coating. Since standard PbO_2 plates were supposed to be used, the difficulty arose that they have only a small capacity when immersed in the acid, which does not reach the desired value until after the first discharge. But, with special treatment of the plates, it became possible to enable them to deliver their full power just a few seconds after immersion. Cells of existing size with 13 pairs of plates supplied capacities corresponding to the 13 T 210 secondary battery in discharges with 1000 A 10 seconds after immersion into the acid. Plus there was about a 25% higher emf over the lead storage battery. But since 18 pairs of Zn-PbO_2 plates were able to be installed in the two trays of the 13 T 210 battery instead of 13 Pb-PbO_2 plates, an overall improvement in power of 70%

was able to be expected. That corresponded to a range of 9000 m at 30 kn and 21% negative buoyancy. With 35% negative buoyancy, as was the case in the E-torpedo with the 17T 210 battery, the G 7e with the $Zn-PbO_2$ battery, which was designated Geraet 42 P [Device 42 P], was to have a range of even 10,700 m at 30 kn. By late 1943 there were six torpedoes ready to be equipped with that primary battery. But it is not known whether it ever came to that and especially whether test firings were conducted. A primary battery based on the $Zn-H_2SO_4-PbO_2$ system is said to have been used in the GOLIATH self-propelled AT mine, according to a report of the Varta AG.

The $Zn-PbO_2$ primary battery admittedly produced only a 35% savings in lead over the Mg-C battery, and for that reason the construction without electrolyte circulation was considerably simpler. On the other hand, the Mg-C battery was still capable of development. If there had been success in making the consumed electrolyte fully active again by continuous reconcentration, a range of 22,000m at 30 kn and 35% negative buoyancy would have been possible. With a more powerful electric motor, it would have still been possible to have a range of 12,000 m at 40 kn. SSW had developed such a motor, but of course it had an additional weight of 360 kg.

Other systems, such as zinc- nickel oxide- potassium hydroxide, cupric oxide- zinc-potassium hydroxide or silver-zinc were also tested at the TVA.

The first, however, proved too weak, while the silver-zinc cell was out of the question, owing to a shortage of raw materials.

Midget Submarine Developments

Besides the TVA, the submarine division K II U in the Design Office was interested in the development of powerful batteries which would extend the submerged range of midget submarines. Development did not begin until the summer of 1944. Even the goal was somewhat different, owing to the considerably longer service duration and the lower current consumption, so that the TVA developments did not lend themselves to be used for that purpose. A metal chlorine battery with platinum plated carbon plates and Almagen-coated zinc electrodes. Chlorinated water with 5% hydrochloric acid added served as the electrolyte. This electrolyte flowed through the battery in the circuit, whereby chlorine from the chlorine tank was added to it in a chlorination apparatus. The electrodes were 400 mm x 230 mm in dimension. The four batteries of the midget submarine SEEHUND was said to accommodate 120 such cells, 60 each connected in series. The service voltage was 90 V, the maximal current intensity, 110 A. It was said to have a continuous rating of 20 kW and 1000 kWh.

An electrolyte exchanger had the function of removing the zinc chloride (about 48 kg/hr) building up in the electrolyte. With a total content of the battery circuit of 480 liters and a permissible maximal concentration of 750 g/l of zinc chloride in the electrolyte, the electrolyte had to be changed every 6 1/4 hrs. During the assumed operating time at full load for 50 hrs, it would therefore have been necessary to renew the electrolyte completely seven times. The electrolyte discharged into the ocean therefore had to be replaced by seawater. 36% remained in one exchanger. After the seventh period, the zinc plates were consumed and had to be changed before the battery could be reused.

Orders for such a primary battery, among others for the chlorine-proof electrolyte centrifugal pumps, were given to the Garvenswerke Company in Vienna for two experimental midget submarines of the SEEHUND type, which were said to have

been built in the Schichau Shipyard in Elbing (presumably U-6251 and U-6252). However, by war's end nothing had been done about installing such an installation in a midget submarine.

Postwar Developments

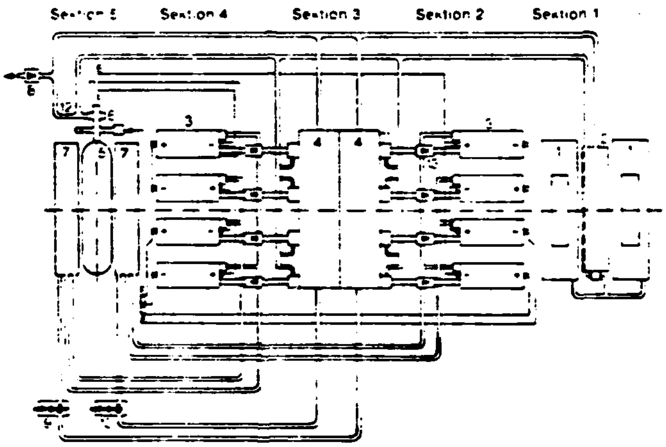
After the Second World War the German developments in the torpedo area were studied carefully and reconstructed with the aid of German experts. But at first only the wakeless torpedo with magnetic influence firing, an acoustic warhead, and wire guidance had an important influence on Allied torpedo construction. In the reorientation of Western armament, motivation for a forced torpedo development was lacking, since the East Bloc was pegged as a solid continental region not dependent on significant supply by seaway. The campaign against the Allied supply lines with the aid of torpedoes however was the important stimulus for the very intensive German developmental work in this area. It turned out that combatting surface ships would be the province of ever more powerful missiles, which were able to replace conventional guns as well as torpedoes. Owing to the incomparably higher speed and greater hit probability at great ranges than the torpedo, missiles are greatly superior to the torpedo here.

With the expansion of the Soviet submarine fleet and the threat proceeding from it there arose a new task for Western torpedo designers in the USA, and that is the development of small antisubmarine torpedoes. In this case, they were able to resume work on the Mk 24 homing torpedo with which German submarines were combatted successfully in the terminal phase of the Second World War. The goal was to develop an electrically powered torpedo with acoustic guidance or wire guidance which is capable of killing submarines in any operating depth. They strove for as light a torpedo as possible for transport to the operations area by aircraft, helicopter, or rocket. Out of the entire selection of light torpedoes produced in the meantime, the US Navy Mk 4 is said to be considered more closely as a typical example of it; it has a diameter of 324 mm, a length of 2560 mm, and a weight of about 233 kg. Its charge consists of about 45 kg of high /320
explosive, which is probably enough to destroy or disable a submarine with a direct hit. In a torpedo of that type, there are about 30 to 35 kg of weight available for the motive power battery. It is obvious that only one battery with a high specific energy content can assure an adequate speed and range. That is the case with the primary battery. However, they did not pick up on the German developments, but at first concentrated on the development of the admittedly more expensive, but perhaps more straightforward silver-zinc battery, which can also be made as a rechargeable storage battery. Such a primary battery has an energy content of about 55 Wh/kg. The so-called seawater battery (magnesium, silver chloride, and seawater) has a considerably higher energy content, specifically about 55 Wh/kg. With it, an energy of 3-3.5 kWh would be available from the whole battery of the light torpedo considered. Therefore, this torpedo could make a run of 6 to 7 min at a speed of about 30 kn, and therefore attain a range of about 5.5 km. That is not really a lot, but should be enough if the torpedo can be brought into the immediate vicinity of the target by a suitable method. This can be done by helicopter, rockets, or large torpedoes (e.g., the G6E KANGAROO of the Italian submarine service).

Another problem is the relative slowness of an electric torpedo. This is the result not only of the limited battery capacity but also of the relatively low power-to-weight ratio of electric motors ($<$1.1 kW/kg compared to 3.5 kW/kg of internal combustion engines). At maximum speed it affords the light electric torpedo only a slight speed advantage or no advantage over present-day submarines.

Substantial improvements in these characteristics can be attained in an electric torpedo only through a major increase in size. A torpedo with conventional dimensions, diameter 533 mm and length, 6-7 m, would be able to hold a seawater battery weighing about 400 kg with an energy content of 40 kWh, and therefore, to attain a range of about 18 km at a speed of over 40 kn. Also the costs of such a large seawater battery are enormous. A figure of \$250/kg is mentioned today for such a battery. That means battery costs for just one heavy torpedo of \$100,000. That is unacceptable, especially for practice purposes. It therefore appears as if the electric torpedo is no longer compatible with the requirements of antisubmarine warfare, and that in the future thermal motive power in torpedoes will take on ever greater importance.

Schematic representation of the VARTA silver oxide/zinc reserve battery for the DM 2 torpedo (VARTA Special Report 1/78, p. 618)



1. Shipboard power supply with two blocks of batteries
2. Electrolyte container for shipboard power supplies
3. Motive power battery with four blocks of batteries of 19 cells each, whose plastic cases are heat sealed and cast in a steel plate casing with casting resin. Each cell has 6 positive electrodes (active material AgO) and 7 negative electrodes (active material Zn)
4. Two electrolyte tanks, which contain the electrolyte (KOH) in heat-sealed plastic bottles
5. Compressed gas cylinder
6. Valve for compressed air cylinder
7. Two lye separators

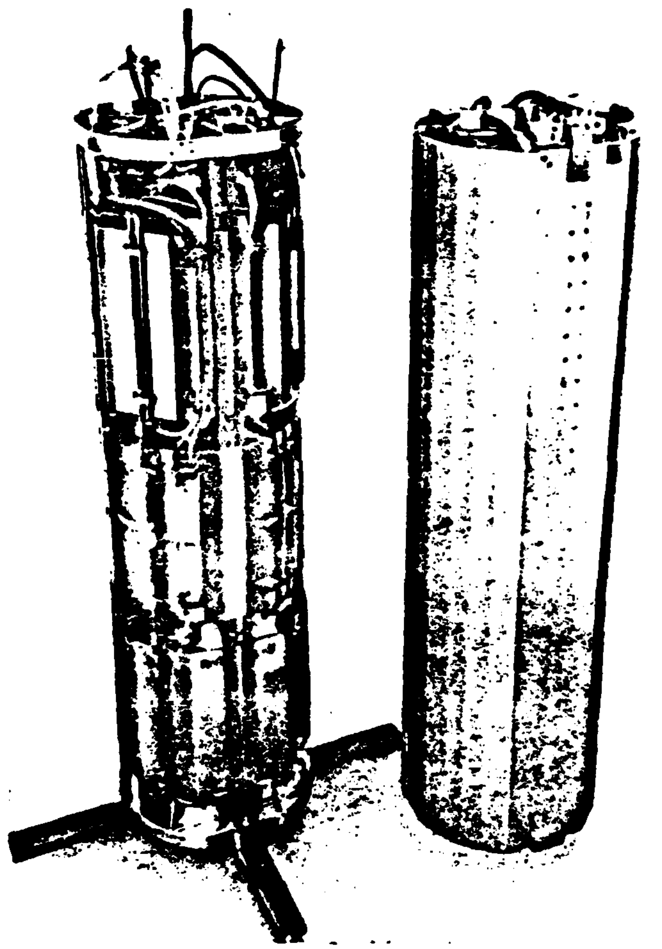
8.-10. Valves

11. Mechanism for opening lye flask
12. Throttle
13. Non-return valve

Sektion = Section

In the Federal German Navy, torpedoes of the former German Navy and of the British Mk standard torpedo were used initially. In the sixties there were added the US Mk 37 antisubmarine torpedo (diameter 438 mm, length 3640 mm, weight 650 kg, range 8000 m/24 kn, German designation DM 3) and the previously mentioned Mk 44 light torpedo.

Starting in 1960, the development began of a German antisubmarine torpedo with the designation DM 1 SEESCHLANGE [SEA SERPENT]. This involves a torpedo with the standard diameter of 533 mm and a length of 3930 mm, which has an acoustic homing device and wire guidance. It is designed for use by submarines (206 Class) and surface ASW ships. There was also the development of a torpedo with a long range against ship targets, which can be employed by submarines or fast patrol boats. In addition, the DM 1 torpedo was lengthened to 5930 mm and partially redeveloped



Battery sections of the DM 2 torpedo
with AgO/Zn reserve battery of the
VARTA Batterie AG firm

to meet the altered mission. This torpedo was given the designation DM 2 SEAL. /321
The two torpedo types have an gO-Zn battery with potassium hydroxide electrolyte and can be made as primary or secondary batteries. A contrarotating electric motor drives the two propellers directly.

In the silver-zinc primary battery, the electrolyte is not injected into the cells by compressed air until immediately before firing of the torpedo. About 8 sec later the motive power battery is then activated. The following character-

istics of an AgO-Zn battery for the DM 2 torpedo were cited by the VARTA Company:

Energy content of whole system:	>55 Wh/kg and 96 Wh/l
Energy content of a single cell:	130 Wh/kg and 247 Wh/l
Energy content of battery block:	92 Wh/kg and 185 h/l.

The charged silver electrode (AgO) can be produced by forming during a charging process with subsequent washing of the electrodes and drying or directly by chemical means. The first method is simpler, but silver electrodes age by forming. Therefore, such cells when new must have an excess capacity of about 40%, if they are to have the rated capacity in 5 years. At the moment, they are talking about a shelf life of 8 years. Thus, about 15% of the whole inventory must be renewed annually. The eliminated torpedoes are used for practice purposes and thus cover about 20% of the practice firings. Then they can be regenerated so that they are again serviceable in a second storage period. For the remaining 80% of the practice firings, special practice torpedoes with O-Zn secondary batteries, therefore storage batteries, are used. In normal use they have a considerably shorter life than lead storage batteries. This significant cost factor resulted in great efforts to lengthen the life of silver-zinc storage batteries using new charing methods. Before their first use, the secondary cells as well as the primary cells are unfilled and uncharged.

The following AgO-Zn storage cells are being used at this time in the German Federal Navy: 20 Ah, 40 Ah, 60 Ah, 90 Ah, and 120 Ah (values for 5-hour discharge and 20°C).

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